TEST RESULTS OF THE ATLAS MARXED PULSED POWER SYSTEM*

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Abstract

Atlas is a pulsed power machine designed to deliver a maximum of 27-32 MA to a load with a rise time of about 5 μs. The machine will be used for hydrodynamic studies in the Los Alamos Nuclear Weapons Program. The load will typically be a metallic cylinder with a mass of about 40 g mounted in a coaxial configuration w.r.t. the current return. Shock pressures of about 15 Mbars can be obtained with a "direct drive" implosion, i.e. simply driving the load liner with its self-generated **JxB** forces.

The energy storage/discharge system for Atlas is composed of 96 Marx modules connected in parallel. For convenience, the Marx modules are arranged into groups of four which we call "maintenance units" (MU's). Two MU's are in a single oil tank so that Atlas has twelve oil tanks. To perform the necessary maintenance on the switches for the Marx modules, a MU will be removed as a unit on a rotating basis. A Marx module is made of four capacitors in series connected by two Maxwell rail gaps which switch the module current into the transmission line to the load. The system is resistively damped to limit voltage reversal on the capacitors and charge transfer through the switches. The capacitors are limited to a 15-20% reversal to meet our lifetime specifications and the switches are limited to a Coulomb transfer of less than 5C. The trigger system for the switches is the equivalent of a Maxwell 40168 and 40108 master/submaster system. The trigger system has been repackaged due to space requirements for Atlas. Maxwell modular power supplies are used to charge each MU with each MU having its own supply.

Results of test on a single Marx module prototype and on the "first-article" MU are presented. The tests are into a dummy load that allows operation at full-erected voltage at equivalent system current and timescale. Results are presented of over 500 Marx module full voltage shots with induced trigger system faults and fault level currents and the first 100 shots on the first Atlas "maintenance unit".

I. TEST PROGRAM

After qualifying the individual components used in the Atlas Marx module, the Atlas energy storage system test program consisted of two main milestones. The first was the testing of the Atlas prototype Marx [1]. This Marx was one of 96 that will be in Atlas. The second milestone is a test of the Atlas maintenance unit which consists of four Marx modules mounted on a common lid. This MU is one of 24. Each MU contains 960 kJ of stored electrical energy. The MU test are necessary because of possible problems caused by the proximity of and increased number of parts compared to the single module. Since most problems will be related to voltage, all testing has been conducted into a load that allows full voltage erection of the Marx modules, whether alone as the prototype, or in parallel as in the MU. Since we operate at full voltage, the actual voltage reversal must be kept under 20%.

In operation in Atlas, the series resistance is such that the Marx modules can not be fired at full voltage without exceeding the 15-20% reversal specification unless damping is provided by the dL/dt of the load. If calculations show that a specific load will not provide sufficient damping, the modules must be fired at a lower charge voltage such that V(erected) + V(reversal) < ~280 kV. Alternatively, we could fire at more than 20% reversal accepting the decrease in capacitor lifetime. This situation allows maximum current to be delivered to a dynamic load. In the prototype Marx, the resistance in the load was provided by Franklin SS resistors. In the MU tests, a steel coaxial load, 24" in diameter with a 6" diameter center conductor is filled with ammonium chloride to provide the needed damping. The prototype Marx was fired at full voltage for 500 shots with no failures. The current was ~300 kA/shot. After the 500 qualifying shots, 10 shots were fired into a 'short' at the entrance to the inductive load to simulate fault conditions. At 600 kA and 25% reversal, no failures were observed. Four trigger failures were then simulated. All of the railgaps erected anyway and no failures occurred.

The MU test program consists of firing ~200 shots into the coaxial dummy load to isolate the MU performance. When this sequence is completed, a terminated Atlas transmission line with its normally closed load protection switch will be mounted to the output of the MU. This sequence of shots will test the transmission line, the load protection switch, and also provide more data for the MU.

We must remove a MU and service the railgaps after ~100 shots. Therefore, we will cycle the railgaps twice before beginning the integrated tests with the transmission line. In addition to the electrical aspects of these tests, procedures for removing, installing and servicing the MU are being developed. To date, we have completed the first 100 shot cycle. The current into the dummy load is 1.4 MA at 240 kV with 15% reversal. (This gives an equivalent Atlas current of 33.6 MA.) The current on all

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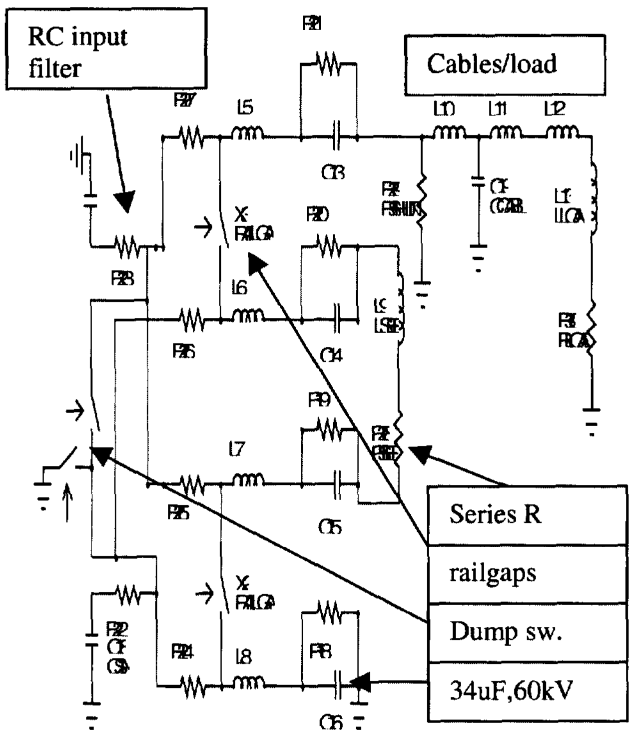


Figure 1. Atlas Marx, one of 96. (4 in parallel = 1 MU)

shots is essentially identical as would be expected since the circuit values are the same. We must wait 15 minutes between shots to allow the stainless steel series resistors to cool. MU tests were begun on 6/8/99. We had two insulation failures due to the proximity of charge and trigger cables, and one failure due to a shorted capacitor. Removal, repair, and installation of the MU takes about a full work day for two technicians. The end result of these tests is to give high confidence for operating Atlas at its full design voltage of 240 kV.

II. CIRCUIT DESCRIPTION

The circuit shown in Fig. 1 is of a single Marx module, without the trigger system circuit connected to a load, with the exception of the 165-kV, 400-Ω resistors. The resistors are necessary to isolate the capacitors when they erect and change polarities. The RC input filter (RC = 160 μs) is to protect the power supply when the Marx erects. Only 28 RG-220 cables go from the cable header to the load in the MU tests to add needed load inductance.

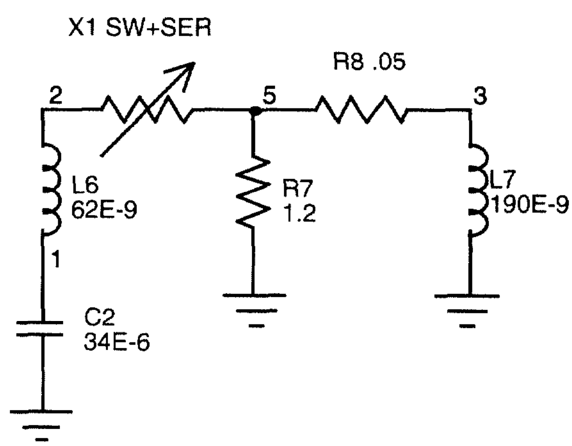
Each capacitor is shorted by a 20 MΩ bleeder resistor. The output of each Marx module is via 14 ea. RG-220 cables to a removable cable header (56 cables/MU). Thus, the MU is removed without having to disconnect any cables. The other side of this cable header stays in the oil tank and will connect to a load protection switch via 56 cables. The normally closed load protection switch is mounted at the rear of a vertical transmission line. Each MU has its own transmission line connected to the radial disk line at the center of the machine.

To accurately model the current from the MU, one must properly account for the varying resistance of the railgaps and stainless steel series resistors. The railgap resistance is modeled using an empirical fit to Tom Martin's model in which R~1/($\int I^{2/3}dt$). The SS resistor has a ΔR due to temperature rise. Using these models for the switch and series resistance, the results are shown in Fig. 3 below. The load in this case is a coaxial inductor filled with ammonium chloride solution with L = 110 nH and R = .05 Ω.

These values allow the MU to be operated at full voltage. The total circuit inductance is ~252 nH. The inductance of the MU is ~78 nH to the cable header. The single Marx module inductance w/o cables is known to be 245 nH from the 500 successful shots fired on the Atlas prototype Marx. Trigger jitter on the MU has not been measured yet but the consistency and shape of the current waveform 20 MΩ safety bleeder resistors, all resistors are 165 kJ, indicate no problem exist. E-dot data is available but has not been analyzed yet.

III. TEST RESULTS

In Fig. 3, the peak current is 1.4 MA at 240 kV erected voltage with a reversal of ~15%. This shot is typical of the 100 full voltage shots fired on the first article MU. In Atlas, each MU will have its own trigger submaster, gas system, charging system, and data acquisition and control



C2=34uF; V=240kV
L(MU)=62nH
L(cables+load)=190nH
L(total)=252nH
R7=R(shunt)=1.2Ohms
X1=R(switch+series)=
37.5mOhms*f(current)
R8=R(load)=.05 Ohms

Figure 2. Circuit used for calculating the current from the First-Article Maintenance Unit.

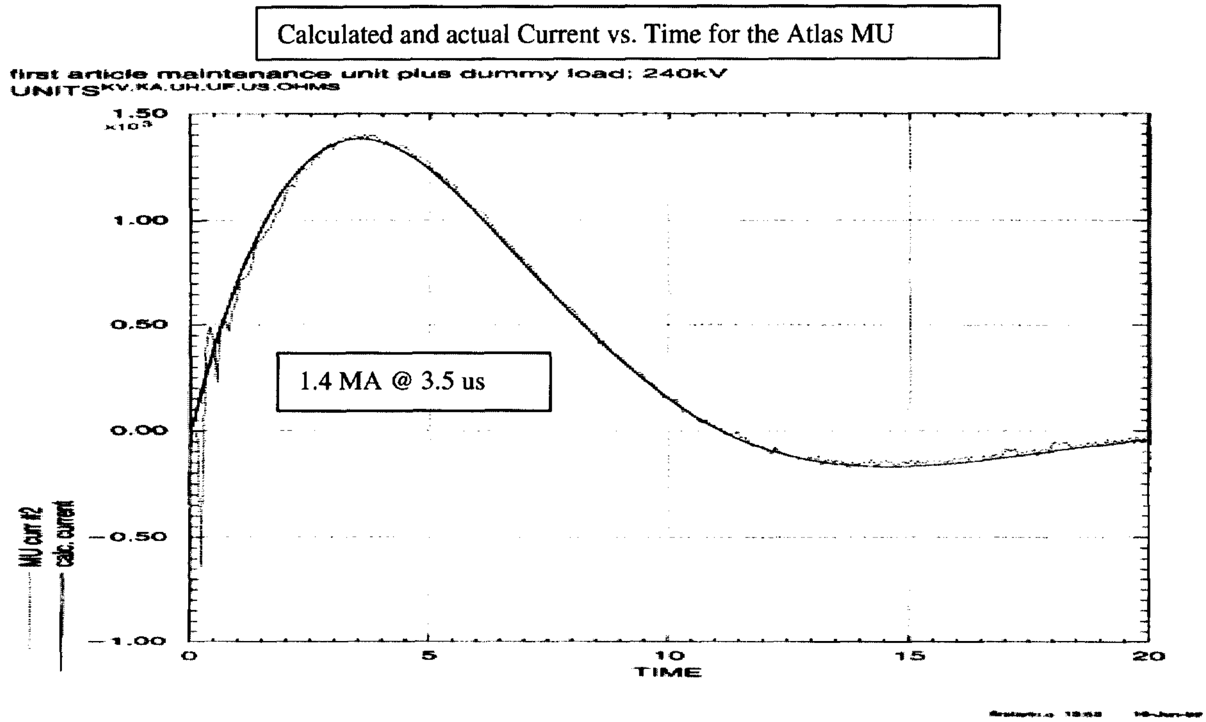


Figure 3. First-Article Maintenance Unit measured and calculated current. (1 shot of 100 to date.)

system. We did not have the Maxwell power supplies or trigger master available for these first tests and could not wait for them. The charging time using the available supply is ~50 seconds instead of the 25 seconds that the Maxwell supplies will provide. This gives a more strenuous test regarding pre-fires and other voltage induced failures since the time at voltage is longer.

IV. SUMMARY

We have successfully tested and modeled the Atlas prototype Marx module under normal and fault conditions with no failures. We have successfully tested and modeled the Atlas maintenance unit, which is 4 Marx modules on a common lid, for a 100 shot maintenance cycle. These tests were all done at the erected design voltage of 240 kV at an equivalent Atlas current of 33.6 MA. The resistance model for the prototype is the same as for the MU. This gives added confidence in predicting system current. We have developed operational procedures that allow rapid removal, servicing, and re-installation of the MU. Given the complexity of the MU and that the weight of the MU is ~10 tons, this is significant and has favorable consequences for Atlas operation. To date, we have not uncovered any basic design flaws in the MU design. Integrated tests using an Atlas transmission line with its normally closed load protection switch is scheduled to begin in July.

REFERENCE

[1] J. C. Cochrane, Jr et.al. "The Atlas Pulsed Power System, a Driver for Producing Multi-Megagauss Fields," presented at VIII International Conference on Megagauss Technology, Tallahassee, FL, 1998.